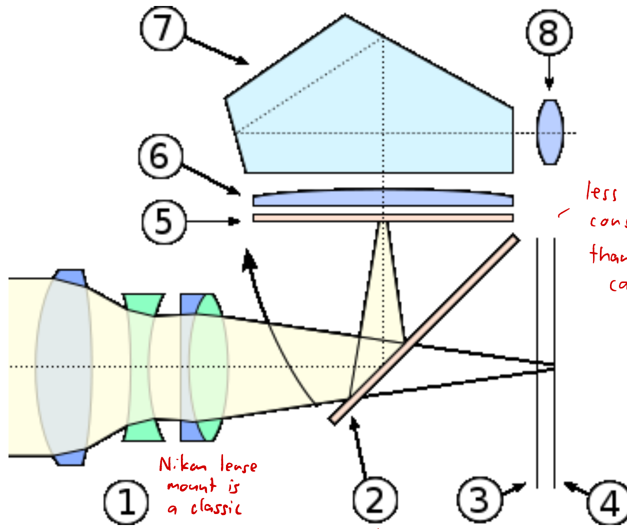
★ FT's & Rep/Comb common exam questions - be sure to review

A Modern Digital Camera



less power consumption than mirrorless cameras

Nikon lense mount is a classic

mirror

shutter sound is from mirror fluctuating

viewfinder

single lens reflex

- Single Lense Reflex (SLR) Camera

  aperture & shutterspeed can be manually adjusted

  – A mirror with a prism allows you to see through through the lense. look through the actual lense you're going to be taking the picture with

  – When photo is taken, mirror retracts to expose film and shutter in lense releases.

- Typical specifications (Nikon D300S)

  – 23.6 mm$\times 15.8$ mm RGB charge coupled device (CCD) sensor

  – 12.3 Meg pixels (million pixels per photo)

  – 100 to 6400 ISO standard measure of sensitivity to the light you're collecting

  – Street price of $\approx$ \$1,500 with lense, flash, and digital media violet, red, then near infrared, far infrared, etc.

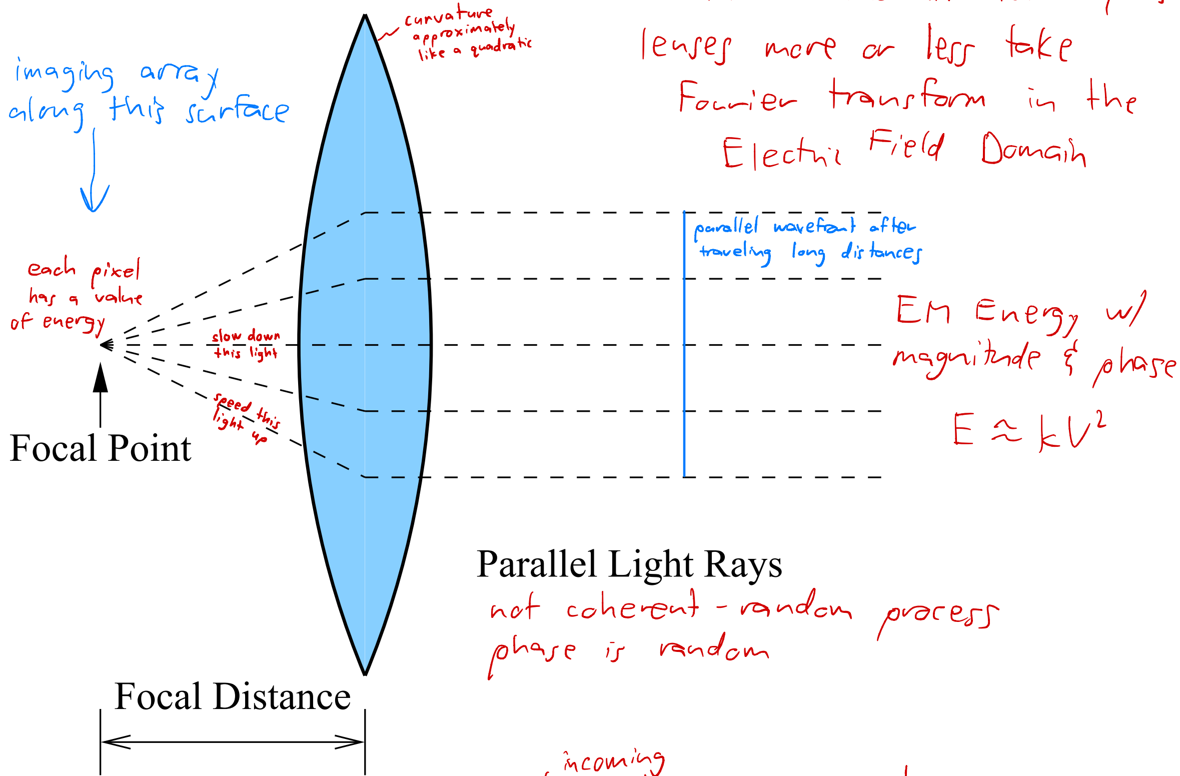
visible light - 400 nm - 700 nm ; 1000 nm = 1 μm

more like a heat map

Lens: Focal Length

rabbit hole: diffractive optics

lenses more or less take Fourier transform in the Electric Field Domain



each incoming angle corresponds to a different angle along the wavefront

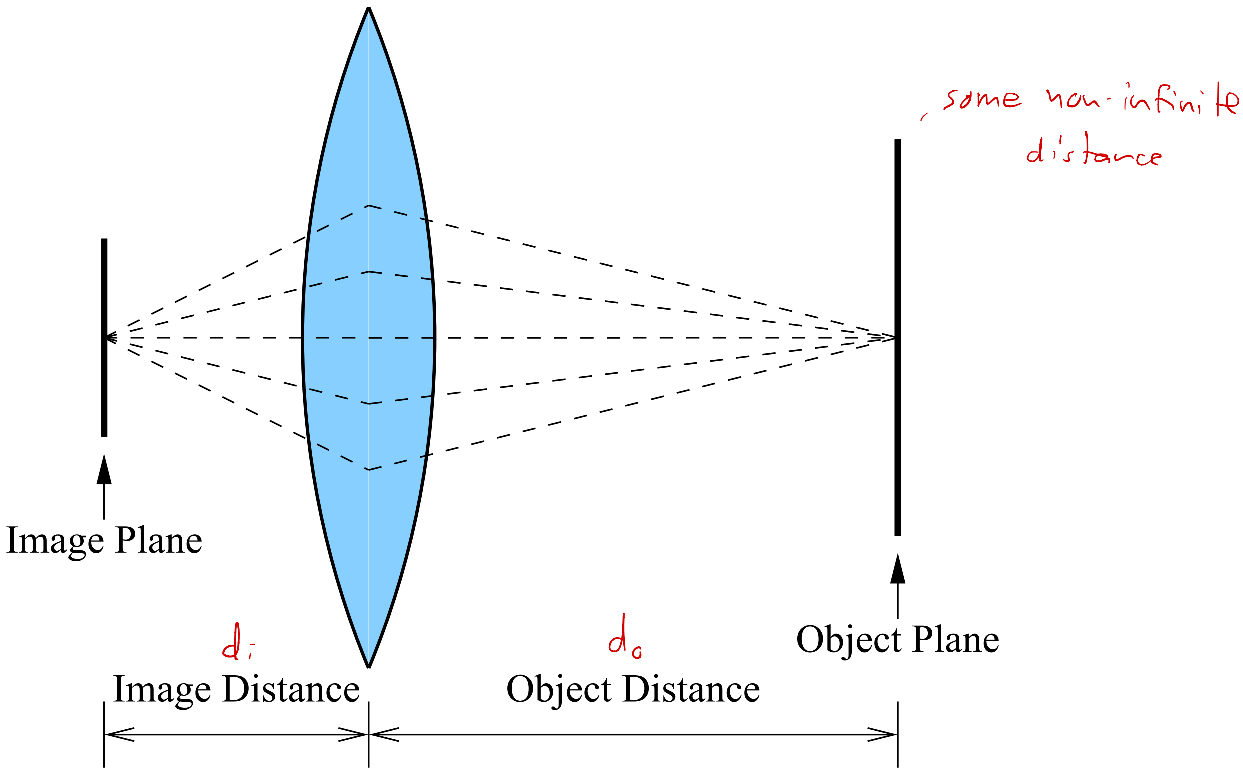
d_f - Focal length of lens

– Focuses incoming parallel rays of light to a point

– Based on a thin lens model

Cell phone towers operate by using FFTs, acts like a lens

Lens: Image Formation



- Quantities:

  d_f - Focal length of lens - lens property

  d_o - Distance to object plane

  d_i - Distance to image plane

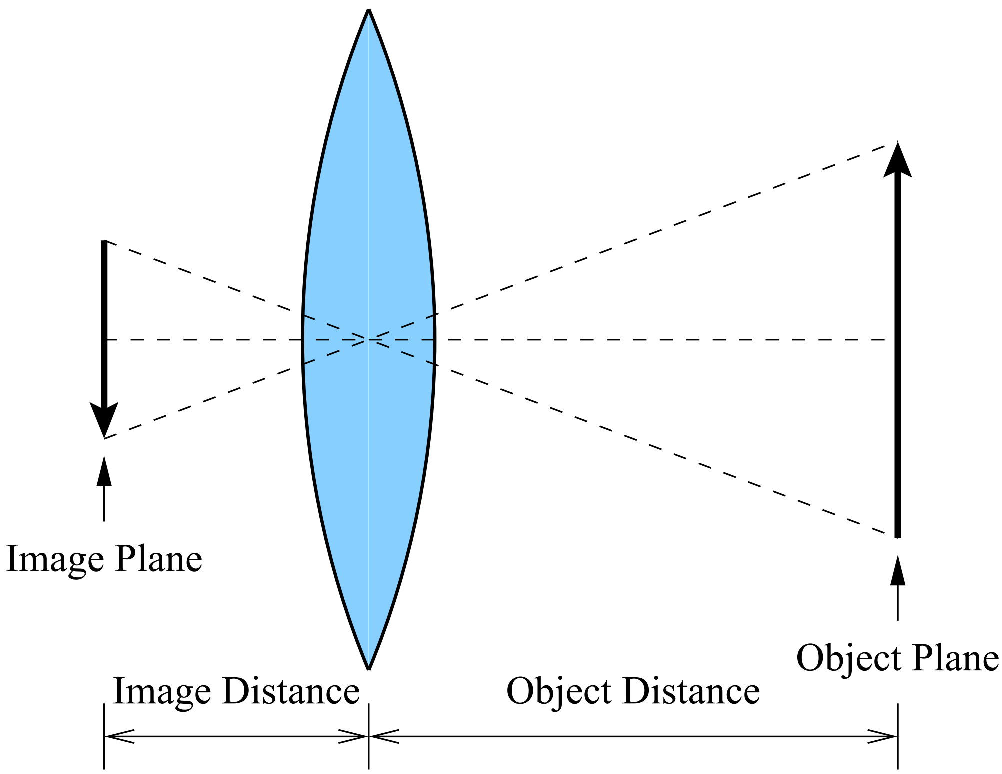
- Basic equation

in order for image to be in focus

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{d_f}$$

Ex: as d_o decreases, d_i must increase either by moving the image plane back or the lens forward

Lens: Magnification



- Quantities:

  d_o - Distance to object plane

  d_i - Distance to image plane

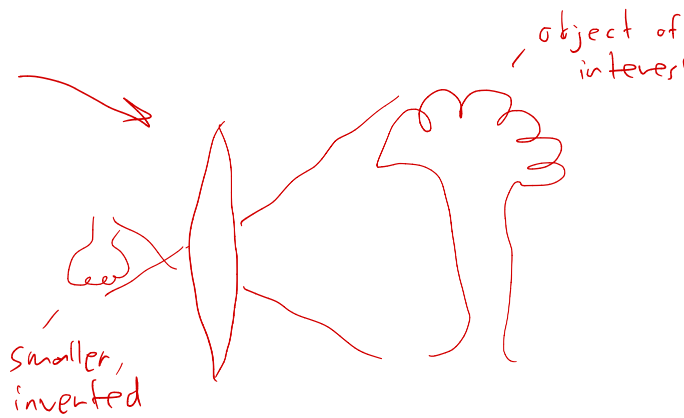
- Basic equation

$$M = -\frac{d_i}{d_o}$$

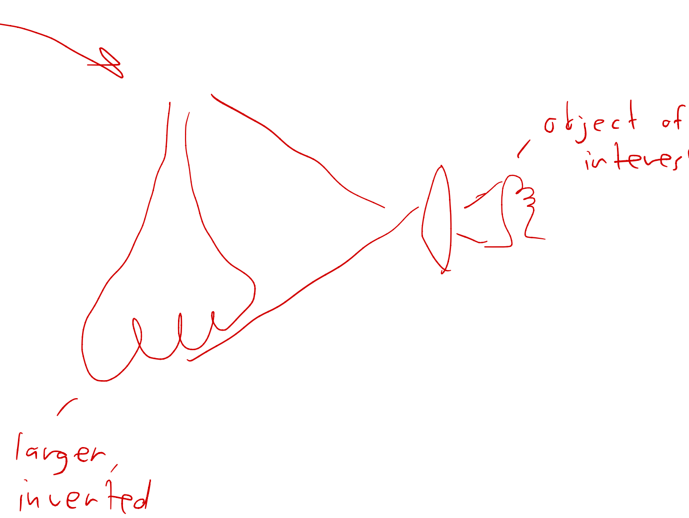
  – Negative sign indicates that image is inverted

Lens: Typical Imaging Scenerios

- Typical case for Photography
  - $d_o >> d_f$
  - $d_i \approx d_f$
  - But in addition $d_i > d_f$
  - $M << 1$



- Typical case for microscopy
  - $d_i >> d_f$
  - $d_o \approx d_f$
  - But in addition $d_o > d_f$
  - $M >> 1$

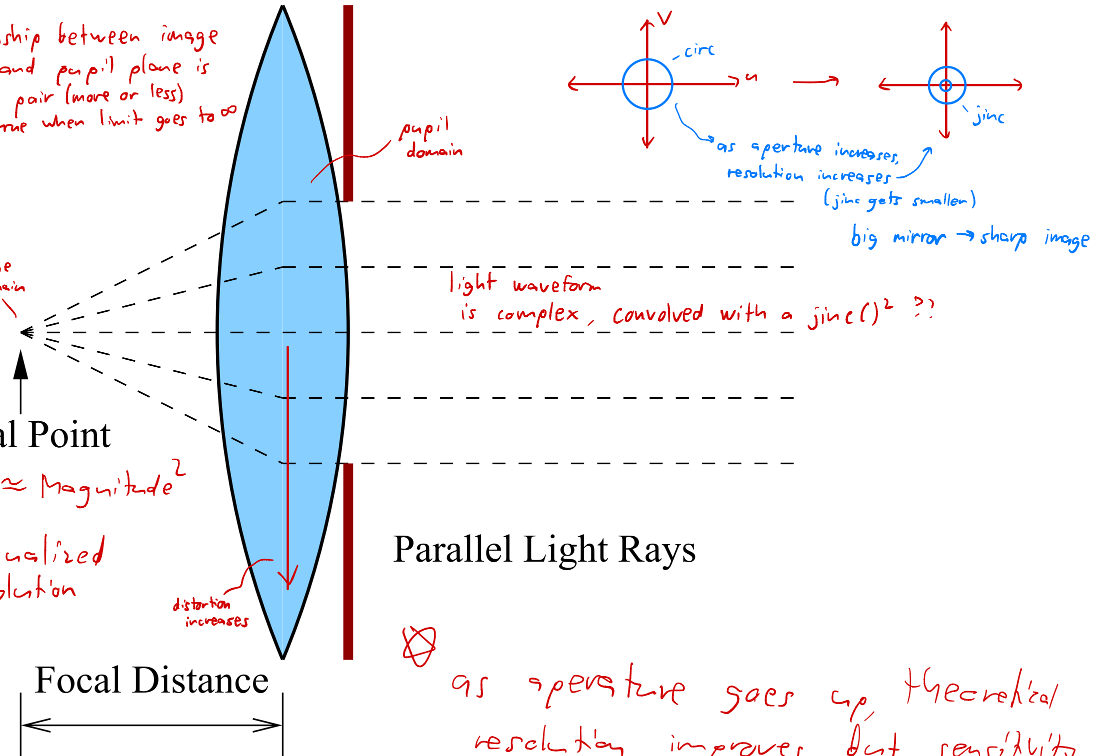


multiplication is frequency is convolution in space domain

Lens: Aperture and f-Stop

high index of refraction → less distortion

relationship between image plane and pupil plane is a FT pair (more or less) holds true when limit goes to ∞



sensing the energy, which is the square of the signal (v^2)

Energy ≈ Magnitude²

energy is visualized after convolution

as aperture goes up, theoretical resolution improves but sensitivity to being out of focus also increases

- Quantities:

  A - Diameter of aperture

  N - f-stop of lens

  d_f - Focal distance of lens

- Basic equation

$$N = \frac{d_f}{A}$$

- relates focal distance of lens and aperture diameter

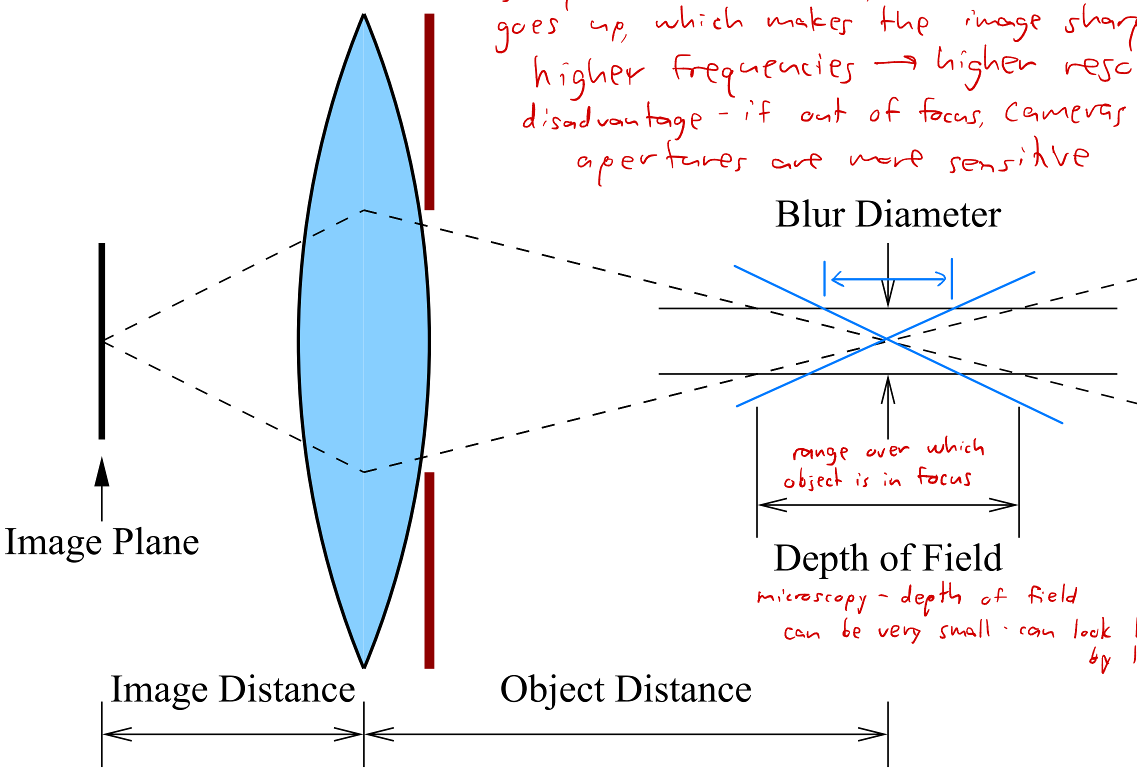
  – Large $N \Rightarrow$ small aperture $\Rightarrow$ slow lens

  – Small $N \Rightarrow$ large aperture $\Rightarrow$ fast lens - more expensive

↳ especially for a zoom or telephoto lens

Lens: Depth-of-Field

as aperture increases, the resolution goes up, which makes the image sharper
higher frequencies → higher resolution spatially
disadvantage - if out of focus, cameras with larger apertures are more sensitive



larger aperture: distance for which image is in focus becomes smaller

- Quantities:

  D - depth of field

  c_o - Blur diameter for object plane

  N - f-stop of lens

  M - Magnification

- If object is far away, then

$$\frac{D}{c_o} = \frac{2N}{-M}$$

  – Small aperture increases depth-of-field

$$h(x) = (f * g)(x) = \int_{-\infty}^{\infty} f(p)\,g(x-p)\,dp = \int_{-\infty}^{\infty} f(x-p)\,g(p)\,dp.$$

Space Domain Models for Optical Imaging Systems

can model a lens as a linear space invariant filter with a point spread function (if you look at the energy)

- Consider an imaging system with real world image $f(x, y)$, focal plane image $g(x, y)$, and magnification M. Then the behavior of the system may be modeled as:

$$g(x, y) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(\xi, \eta)h(x - M\xi, y - M\eta)d\xi d\eta = (f*h)(x,y)$$

substitution?

$\xi \to \frac{\xi}{M}$

$\eta \to \frac{\eta}{M}$

$$= \frac{1}{M^2}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f\left(\frac{\xi}{M}, \frac{\eta}{M}\right) h(x - \xi, y - \eta)d\xi d\eta$$

Define the function

$$\tilde{f}(x, y) \triangleq f\left(\frac{\xi}{M}, \frac{\eta}{M}\right)$$

equivalent to

- Then the imaging system act like a 2-D convolution.

$$g(x, y) = \frac{1}{M^2}h(x, y) * \tilde{f}(x, y)$$

Point Spread Functions for Optical Imaging Systems

- Definition: $h(x, y)$ is known as the *point spread function* of the imaging system.

$$g(x, y) = \frac{1}{M^2} h(x, y) * \tilde{f}(x, y)$$

- Notice that when $f(x, y) = \delta(x, y)$

$$\begin{aligned} g(x, y) &= \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \delta(\xi, \eta) h(x - M\xi, y - M\eta) d\xi d\eta \\ &= h(x, y) \end{aligned}$$

recall: $g(0) = \int_{-\infty}^{\infty} \delta(t) g(t) dt$

$\hookrightarrow g(x, y) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \delta(\xi, \eta) h(x - M\xi, y - M\eta) d\xi d\eta = h(x - 0, y - 0)$

$= h(x, y)$

Transfer Functions for Optical Imaging Systems

- In the frequency domain,

true because of convolution property of FT's

$$G(u,v) = \tilde{F}(u,v)\,\frac{1}{M^2}H(u,v)$$

$$g(x,y) \overset{CSFT}{\Leftrightarrow} G(u,v)$$
$$h(x,y) \overset{CSFT}{\Leftrightarrow} H(u,v)$$
$$\tilde{f}(x,y) \overset{CSFT}{\Leftrightarrow} \tilde{F}(u,v)$$

- The *Optical Transfer Function (OTF)* is

$$\frac{H(u,v)}{H(0,0)}$$

- The *Modulation Transfer Function (MTF)* is

more commonly used because more practical according to Dr. Bouman

$$\left|\frac{H(u,v)}{H(0,0)}\right|$$